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AN ASSESSMENT OF A FEDERAL REGULATION TO CURTAIL "SUNDOWN" SETS INVOLVING MARINE MAMMALS BY THE U.S. TUNA PURSE-SEINE FLEET

By

James M. Coe and Charles W. Oliver

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ADMINISTRATIVE REPORT LJ-91-20

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AN ASSESSMENT OF A FEDERAL REGULATION TO CURTAIL "SUNDOWN" SETS INVOLVING MARINE MAMMALS BY THE U.S. TUNA PURSE-SEINE FLEET

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Introduction

Under the Marine Mammal Protection Act[1] of 1972 (MMPA), the National Marine Fisheries Service (NMFS) is responsible for maintaining and protecting the stocks of dolphins incidentally involved in the United States tuna purse-seine fishery.[1] The principal dolphin species involved in this fishery are the spotted dolphin, Stenella attenuata, the spinner dolphins, Stenella longirostris, the common dolphin, Delphinus delphis, and the striped dolphin, Stenella coeruleoalba. In carrying out this responsibility a number of gear and procedural regulations, as well as kill quotas, have been enacted. By 1979, the total incidental dolphin mortality and serious injury had been reduced approximately twenty-fold from an estimated 368,600 in 1972 to about 18,000 (Smith 1979[2]) for the U. S. eastern tropical Pacific fishery. In January 1981, in its continuing effort to reduce the dolphin kill rates, NMFS enacted a series of additions to the existing regulations governing the take of marine mammals by the U.S. tuna purse-seine fleet during the 1981 through 1985 seasons. Among these was a regulation designed to eliminate net sets involving marine mammals in which the primary rescue operation, known as the backdown procedure (Coe and Sousa, 1972), occurs in the dark (50 CFR 216.24(d) (2) (vii)(g)). This regulation required that sets involving marine mammals not be initiated (net skiff released or "net let go") within 90 minutes of local sunset and is, in effect, a daily limitation on fishing effort (NOAA 1980a[3], NOAA 1980b[4]).

The regulations which enacted the "sundown set" prohibition also allowed the prohibition to be placed in abeyance (50 CFR 216.24(d) (2) (i) (D)), due to uncertainty over its impact on tuna catch rates and its expected efficiency in eliminating sets where the backdown procedure would occur in the dark. To address these uncertainties we conducted a series of analyses. This paper examines the basis for the proposed 1981 regulation, estimates its impact on tuna catch and dolphin kill, and addresses its expected efficiency in reducing dolphin mortality for the period 1977-1980. The prohibition on "sundown sets" remained in abeyance through 1988, but with passage of the Marine Mammal protection Act Amendments of 1988 (Pub. L. 100-711) additional "sundown set" analyses were performed using data collected during 1979-1988 (Coan et al., 1988[5]). The NMFS proposed a modified "sundown set" regulation in 1988 which became effective in 1989 (50 CFR(d) (2) (vii) (C)). As with the original "sundown set" regulation, the intent of the new regulation is to eliminate net sets involving marine mammals in which the primary rescue operation, known as the backdown procedure occurs in the dark. We present our analyses of data collected during 1977-1980, in the context of the original "sundown set" regulation, in the hope of providing additional insight as to why dolphin mortality is increased during "sundown sets", and their effect on annual dolphin kill and tuna catch.

Methods

Database extractions:

To facilitate these analyses, it was necessary to create a database by merging data from the National Marine Fisheries Service (NMFS) and Inter-American Tropical Tuna Commission (IATTC) observer cruises into a fixed, computer-accessible format. The database is a consolidation of coded field data collected by NMFS and IATTC observers aboard United States-flag tuna purse-seine vessels operating in the eastern tropical Pacific. It contains data collected by NMFS observers aboard vessels fishing during the period 1977 through 1980, (345 trips). The IATTC data includes trips beginning in 1979, when IATTC observers began collecting data on dolphin mortality, through those that were available as of March 1981 (53 trips). This sample represents a portion of all United States-flag trips in the eastern tropical Pacific (104 of 494 in 1977, 118 of 501 in 1978, 112 of 600 in 1979, and 64 of 609 in 1980)[6].

The database is structured so that each setting of the purse-seine net is reflected in a logical set record. Each logical set record consists of five 80-column, formatted physical records that contain the variable values. Each physical record is uniquely identifiable as is each logical record. These data are currently stored on the computer system at the Southwest Fisheries Center, La Jolla, CA. Table 1 shows the number of cruises, by year, for both NMFS and IATTC data that are contained in the database.

The times of certain celestial events (sundown, civil and astral twilight) were computed for each set and entered into the database to permit analyses of the distribution of time intervals for fishing activity events relative to the period of deepening twilight that begins with sunset and ends at complete darkness. A computer algorithm was written based on mathematical formulae in Bowditch (1966) which computed the local apparent times of sunset, the end of civil twilight and the end of astronomical twilight. The algorithm calculates these times using the vessel position and date and is accurate to $\pm$ 3 minutes for locations between 30° north and 30° south latitudes. These celestial events are defined in the Smithsonian Meteorological Tables (List, 1949) as follows:

> Sunset (sunrise): considered to occur when the upper edge of the disk of the sun appears to be exactly on the horizon with an unobstructed horizon and normal atmospheric refraction.
>
> Civil Twilight: the interval between sunrise or sunset and the time when the true position of the center of the sun is 6° below the horizon, at which time the stars and planets of the first magnitude are just visible and darkness forces the

suspension of normal outdoor activities.

Astronomical Twilight: the interval between sunrise or sunset and the time when the true position of the center of the sun is 18^{o} below the horizon, at which time stars of the sixth magnitude are visible near the zenith and generally there is no trace on the horizon of the twilight glow.

Table 2 shows the summary statistics for the times of these celestial events for all observed dolphin sets in 1979. The only source of error in these calculated times would be erroneously recorded dates or locations. There is no measurement of the frequency of such recording errors. However, the frequency is believed to be low and therefore the time between "net let go" and sunset can be assumed to be accurately calculated for each set in the database. By this method, the distribution of "let go" times in the sample can be standardized to any of the celestial events without regard to variations in date or geographic position.

Time Corrections:

An accurate assessment of the effects of prohibition of "sundown sets" further requires that the "net let go" time recorded by the observer be correct for the time zone in which the vessel was located, since the calculated sunset times are for that time zone. There are two sources for this kind of time- recording error. The first, and probably most common, derives from failure to adjust the vessel's clocks (boat time) when a new time zone is entered. Observers are instructed to use boat time on their data forms, hence the error is transferred. The second source of error stems from the observer's failure to accurately convert the time shown on his watch to 24-hour clock time.

Fortunately, enough information was available to make some corrections in "net let go" times for sets that occurred late in the day: the recorded time that backdown ended, the calculated time that normal outdoor activities are suspended (end of civil twilight) and, for all NMFS cruises and some IATTC cruises, data to indicate whether or not part or all of the backdown took place in the dark. A priori, we assume that all observers would record any backdown ending more than 15 minutes after the end of civil twilight as having occurred in darkness, and any backdown ending more than 15 minutes before the end of civil twilight as having occurred in daylight. Using this assumption, each set was examined to see if 1) a "daylight backdown" was recorded later than 15 minutes after the end of civil twilight or 2) a "darkness backdown" occurred more than 15 minutes before the end of civil twilight. Sets which fell in the first category had their "net let go" times reduced by 2 hours if backdown ended more than 75 minutes after sunset, and by 1 hour if backdown ends between 16 and 75 minutes after sunset. This adjustment is reversed for sets which fall into the second category. Figure 1 shows the

1979 distribution of "end of backdown" times for "daylight backdown" and "darkness backdown" relative to the end of civil twilight before the time correction. The "net let go" times were made earlier for 51 darkness sets and later for 7 daylight sets representing an adjustment of 3 percent of all sets in the database. Figure 2 shows the new distribution after the times were adjusted.

This method of adjusting recorded times only corrects sets with obvious discrepancies. The data do not permit further corrections so that some errors in the classification of sets by the recorded time "net let go" may exist in the analyses. The validity of "net let go" times that reportedly finished backdown either later than the end of civil twilight minus 15 minutes and were actually performed in darkness, or earlier than the end of civil twilight plus 15 minutes that were actually performed in daylight, cannot be assessed. This method for adjusting "net let go" times, as tested on the 1979 data, was applied to all sets in the database (1977-80).

Stratifications:

For the following analyses, the sets in the database involving marine mammals are classified into four overlapping categories. Early in this exercise it became apparent that these categories must be specifically named and clearly defined. First, the entire sample of sets involving marine mammals is divided (data permitting) into two mutually exclusive subsets; 1) "darkness sets" are those in which part or all of the backdown release procedure was executed in the dark (as judged by the observer), 2) "daylight sets" are those sets in which the entire backdown was carried out in daylight (as judged by the observer). This division is made to facilitate an assessment of the basis of the regulation (i.e., the contribution to the total marine mammal mortality from darkness sets). The second division of the sample of sets on marine mammals is based on the regulatory requirement prohibiting set initiation at 90 minutes prior to sunset. The 90-minute cut-off reflects the mean time (87.5 minutes) necessary to proceed from set initiation to the completion of backdown during 1979 for sets that "let go" at 1630 hours or later (Table 3). This interval ranged from 50 to 266 minutes indicating that no specific cut-off time can satisfy the intent of the regulation completely. Two mutually exclusive categories result from this second division: 1) "sundown sets" are those sets in which the time the set was initiated (net skiff released or "net let go") 90 minutes or less before the local apparent time of sunset and hence would have been prohibited by the regulation; 2) "non-sundown sets" are those initiated more than 90 minutes before the local apparent time of sunset and would not have been prohibited by the regulation.

The regulation-defined "sundown sets" and "non-sundown sets" categories include both "daylight sets" and "darkness sets". This

division of the sample enables the calculation of what the impact of the prohibition would have been in the years represented in the sample. Comparison of the four categories yields an assessment of the degree to which the regulation would have achieved, or failed to achieve, its intended goal in the years represented in the sample, that is, its efficiency.

Results

The sampling plan for the U.S. tunaboat observer program has been carefully designed and executed (Lo, et al. 1982; Lo, 1983) so that one can reasonably expect the data from observed vessels for a complete year to accurately represent the performance of entire U.S. fleet for that year. The database contains complete observer data for 1977 through 1979 but is incomplete for 1980. Wherever the subsequent tables and figures include results derived from the 1980 data they should be considered as preliminary. Only those sets which 1) captured dolphins, 2) included date and position data, 3) did not involve an equipment malfunction, and 4) had a record of whether or not back down took place in the dark are included in the analyses. The first three requirements had no effect on the sample of sets needed for this investigation. However, the fourth requirement (daylight versus darkness during backdown) reduced the sample size, by 896 sets in 1979 and 425 sets in 1980, because IATTC observers did not commonly record that datum. It is assumed that these excluded sets, as well as their tuna catch and dolphin kill, are distributed similarly to those used in the analyses.

After calculating the local time of sunset for each set and correcting for time-recording errors, sets meeting the criteria for inclusion were stratified according to whether the "net let go" time was before or after sunset minus 90 minutes, and whether the backdown occurred in daylight or darkness. The distribution of sets, catch of yellowfin tuna, and dolphin kill were computed for each of the stratifications. These distributions are presented for 1977-1980 in Tables 4-6. The stratified distributions of dolphin kill-per-set, dolphin kill-per-ton, and catch-per-dolphin-set (tons yellowfin tuna) for 1977-1980 are shown in Tables 7-9. We summarized the percentages of dolphin sets, yellowfin tuna catch, and dolphin kill for each of the four strata, and their combinations, in Tables 10a-d for 1977, 1978, 1979, and 1980, respectively. Table 11 presents the stratified percentages of sets where more than 15 dolphins were killed. Table 12 presents estimates of the yellowfin and skipjack tuna caught during 1977-1980. Table 13 shows the cumulative average observed dolphin kill and tuna catch, in ten-minute intervals, for sets that occurred between 130 minutes prior to, and after, the local time of sunset for the period 1977-1979. This table shows the expected impact on kill and catch at alternative times of prohibition using a cumulative average versus an annual average dolphin kill, or tuna catch, for the period 1977-1979. Tables 14-16 present dolphin kill-per-set data for the most

effective and least effective vessel operators. These tables (4-16) summarize the necessary data for assessing the basis for, and the impact and efficiency of the regulation curtailing purse-seine fishing for tuna in association with marine mammals within 90 minutes of sunset.

Basis for the regulation:

Figure 3 illustrates the contributions that darkness sets and "sundown sets" made to the total observed catch of dolphin-associated yellowfin tuna (Thunnus albacares), the total number of sets on marine mammals, and the total observed dolphin kill for 1977-80. This figure shows that the percentage of sets and percentage of catch are about equal for each year, whereas the percentage of observed dolphin kill attributed to darkness sets increased from 1977 to 1979 (14.1% in 1977 to 48.3% in 1979) and may decreased in 1980 (45.3%). The kill-per-sets in observed darkness and daylight sets, respectively, were 6.5 and 2.8 in 1977, 12.8 and 3.0 in 1978, 12.0 and 1.8 in 1979, and 14.1 and 2.2 in 1980 (Table 7). The disparity between kill-per-tons of yellowfin tuna in darkness and daylight sets is similar to that exhibited for kill-per-sets as shown in Table 8 (0.5 vs 0.2 in 1977, 1.0 vs 0.2 in 1978, 0.9 vs 0.2 in 1979, and 1.3 vs 0.2 in 1980).

For the purpose of examining the causes of dolphin kill, we classified sets with a dolphin kill greater than 15 as "problem sets." The percentages of "problem sets" in the darkness and daylight sets samples were computed (Table 11). While the frequency of daylight sets with a kill of 16 or more was cut in half from 1977 to 1980 (4.0, 3.0, 2.4 and 2.0%, respectively), the "problem set" frequency in darkness sets did not show a similar reduction and, in fact, increased slightly from 1977 to 1979, while decreasing in 1980 (12.4, 13.3, 14.0 and 11.2%, respectively).

The mean contributions to total catch and dolphin kill by darkness sets were computed from Tables 4-6 for the 3 complete years in the database (1977 to 1979). For these 3 years, the mean annual frequency of darkness sets was 9.3%, accounting for 28.7% of the mean annual total kill of dolphins, and 9.6% of the mean annual total yellowfin tuna taken in association with marine mammals. Clearly, sets in which the backdown procedures occurred, either partially or entirely, during darkness accounted for a significant share of the total dolphin kill during the period 1977-1980. While that share increased considerably during 1977-1979, and possibly declined in 1980, the amount of tuna taken in these sets and the number of sets during 1977-1980 varied only slightly (Figure 3).

Impact of the regulation:

The curtailment of fishing activities involving marine mammals at 90 minutes prior to sunset will result in a reduction of the number of net sets made on marine mammals, and hence the tuna catch and dolphin kill will be reduced. In order to estimate the potential impact of this curtailment, a post hoc application of the sundown set regulation was made to the data base and the impacts are expressed as percentages of annual totals for dolphin kill and tuna catch. Tables 10a-d and Figure 3 show the percentages of total kill and tuna catch resulting from sets that would have been prohibited (sundown sets) for the period 1977-1980. In 1977, 9.5% of the sets on dolphins, accounting for 9.2% of the yellowfin tuna catch associated with marine mammals, and 16.1% of the dolphin kill would have been eliminated. In 1978, 10.7% of the dolphin sets, 11.1% of the yellowfin tuna catch associated with marine mammals, and 28.8% of the dolphin kill would have been eliminated. For 1979, 15.2% of the dolphin sets, 17.0% of the yellowfin catch associated with marine mammals, and 51.8% of the dolphin kill would have been eliminated. During 1980 (incomplete) 13.8% of the dolphin sets, 13.0% of the yellowfin catch associated with marine mammals, and 22.0% of the dolphin kill would have been eliminated.

The mean annual impact of this curtailment was calculated for our sample from Tables 10a-c for the three complete years in the data base (1977 to 1979). If the regulation had been in effect during that period, 11.5% of the sets on marine mammals would have been prohibited, accounting for 30.0% of the total dolphin kill and 11.9% of the yellowfin tuna taken in association with dolphins. It should be noted here that 96.7% of the total tuna taken with dolphins in the 1977 through 1979 sample was yellowfin tuna, and 3.3% was skipjack tuna (Katsuwonus pelamis). It can reasonably be assumed that no more than 11.9% of the skipjack tuna taken with dolphins during 1977 through 1979 would have been eliminated by the regulation.

Assuming that observed performance accurately represents overall fleet performance for tuna catch and dolphin kill, the above percentages may be applied to any expected annual U.S. tuna catch or dolphin kill to yield estimates of the impact of the prohibition against initiating a set on marine mammals within 90 minutes of sunset. Using the estimated total annual catch of tuna taken by U.S.-flag purse-seiners (Table 12)[6], the 1977-1979 mean annual loss in tuna catch was determined.. We calculated the 1977-1979 average yellowfin tuna catch, taken on dolphin herds, to be 69,164 short tons per year and the mean skipjack tuna catch to be 2,261 short tons per year (Table 12). Applying the percentage for catch loss derived above, the mean annual total tuna loss due to the prohibition is computed to be 8,231 short tons of yellowfin tuna (69,164 x 11.9%) and 269 short tons of skipjack tuna (2,261 x 11.9%). Table 12 provides the 1977-1979 average U.S. catch of yellowfin and skipjack tuna as 204,643 short tons. The annual U.S. catch would have been reduced an

estimated 4.2% if the sundown set prohibition had been in force in 1977 through 1979, while the annual dolphin kill would have been reduced by 30.0%, or approximately 6,190 animals.

Assuming this estimated loss in tuna catch would be evenly distributed among the over 100 seiners in the U.S. fleet, the impact, however unpleasant, would not be catastrophic. The loss would probably not be evenly distributed since some vessels and captains rely more heavily on dolphin associated tuna for their livelihood. Furthermore, the financial situation of any particular vessel may be such that the inability to take advantage of several dolphin schools with high concentrations of tuna encountered late in the day may lengthen a trip enough to make it unprofitable. Several such trips could bankrupt the vessel. The probable result of the sundown set regulation would be the demise or transfer to foreign interests of a few financially unhealthy vessels each year, a modest increase in the price of canned tuna to the consumer, or both. A significant decrease in annual dolphin mortality would also have resulted from the regulation.

Efficiency of the regulation:

The intent of the sundown set prohibition is the elimination of sets involving marine mammals in which all or part of the backdown release procedures are performed in the dark, and thereby a reduction in dolphin mortality. Tables 10a-d and Figure 3 illustrate how well the regulation would have performed during 1977-80. The percentage of darkness sets that would not have been prohibited (i.e., were initiated prior to sunset minus 90 minutes) ranged from 5.1% (1980) to 9.2% (1978). Using the 3 years of complete data from 1977 to 1979, the average frequency for non-prohibited, darkness sets would have been 7.1% of the total darkness sets (0.7% of the total sets), accounting for 6.2% of the total kill in darkness sets (0.2% of the total kill), and 6.2% of the catch of yellowfin tuna during darkness sets (0.6% of the total catch). Therefore, the regulation would have been 92.9% effective in eliminating darkness sets during 1977-1979.

The regulation would also have eliminated a substantial number of sets where backdown occurred during daylight (Tables 10a-d and Figure 3). In 1977, 3.0% of the observed sets on dolphins catching 2.4% of the total yellowfin tuna in association with dolphins, and accounting for 1.7% of the dolphins killed would have been eliminated. In 1978, 2.6% of the sets, 3.0% of the catch and 1.4% of the kill would have been eliminated. In 1979, the impact would have been 3.2% of the sets, 3.3% of the catch and 6.7% of the kill. The annual averages for the 3 years were 2.9% of the dolphin associated sets, 2.4% of the catch and 2.2% of the kill. Due to the range of set durations from initiation to the end of backdown in the fishery, setting the prohibition at 90 minutes before local sunset is on the conservative side of the distribution by eliminating four times (2.9% - 0.7%) more

daylight sets than it would have permitted darkness sets during 1977-1979.

Also of interest is the major difference in the percent of total dolphin kill that the prohibition would have eliminated in 1979 (51.8%) and in 1980 (22.0%) as shown in Tables 10c and 10d and Figure 3. This difference is due largely to a single set during 1980 which had backdown occurring in the dark but would not have been eliminated by the prohibition because the "net let go" time was before sunset minus 90 minutes. This set killed over 800 dolphins, accounting for about 22% of the kill in the 1980 sample. This example serves to illustrate the fact that the efficiency of prohibition could vary considerably between years. Those sets that are initiated before sunset minus 90 minutes with backdown occurring during darkness are also those that take an abnormally long time from "net let go" to the end of backdown (at least 112 minutes; 90 minutes to sunset plus approximately 22 minutes to the end of civil twilight). Malfunctions and other complications normally cause this protracted interval, so these sets are in the high-risk category with respect to dolphin kill. We eliminated sets where equipment malfunctions were recorded prior to these analyses. The converse of this phenomenon is expected to be true for daylight sets that "let go" after sunset minus 90 minutes. In 3 of the 4 years examined (1977-1979), the kill-per-set in prohibited sets that had daylight backdown was less than in non-prohibited sets with daylight backdown (Table 7).

Effects of changing the time of the proposed prohibition:

In order to provide a means of estimating the potential effects of the time of the prohibition on tuna catch and dolphin killed, Figures 4 through 7 were prepared. These figures show the cumulative dolphin-associated tuna catch (yellowfin and skipjack) and cumulative dolphin kill for sets initiated between 30 minutes after sunset and 130 minutes before sunset, by "net let go" times in 10-minute intervals. Figures 4 and 5 are for observed sets in 1979 and Figures 6 and 7 show the averages for the 3 complete years (1977-1979) in our data base. Because of the variability of catch and kill between years (illustrated by comparing 1979 to the 3-year average), the best long-term estimate of the effects of changing the time of the prohibition can be derived from the 3-year averages presented in Figures 6 and 7 and summarized in Table 13. Again, it is assumed that observed performance accurately represents overall fleet performance for catch and kill such that the percentages in these figures may be applied to any expected annual United States tuna catch of dolphin kill to yield estimates of the impact of the time of prohibition. For example, if the prohibition were set at 130 minutes before sunset, interpolation of Figures 6-7 and Table 13 indicates a reduction in total annual dolphin kill of about 31% and a loss of about 16% of the total annual tuna catch on porpoise. For the 3 years included in Figure 6, skipjack

represented 3.3% of the total tuna taken in association with marine mammals. If the total tuna catch with dolphins in any particular year was expected to be 90,000 tons but a prohibition against sets less than 130 minutes prior to sunset were enacted, only 75,600 tons (85% of 90,000) would be landed. The estimated loss in catch under these circumstances would be 14,400 tons comprising 13,925 tons of yellowfin and 475 tons of skipjack. A kill reduction of 26.2% and a catch reduction of 10.5% would have resulted if the present regulation prohibiting sets after 90 minutes before sunset had been in effect (Table 13).

Operator performance and the potential for training:

The intent of this section is to characterize the potential for reducing the kill rates in darkness sets through increased education and training programs with no attempt to design such programs or estimate their likelihood of success. Because the recipient of any proposed education effort is the vessel operator, the range and characteristics of individual operator performance were analyzed. Basic to this analysis is the assumption that the difference between the performance of operators is a function of experience and motivation, both of which can presumably be imparted through education and training.

To reduce the effects of short-term phenomena (accidental events or "bad luck") in the assessment only operators that performed at least 8 sets with all or part of the backdown procedures occurring during darkness (darkness sets) were included in these analyses. The data base has 162 observed operators, 151 of whom made at least one dolphin set and 123 of whom made at least one darkness set. Of these, 34 had at least 8 sets in which backdown occurred, either partially or entirely, in the dark and were ranked by their overall average kill-per-set record. The 10 operators with the lowest average kill-per-set rates and the 10 with the highest average kill-per-set rates are shown in Tables 14 and 15, respectively. The mean kill-per-set for daylight and darkness sets for these operators are assumed to indicate the spread of the fleet's capabilities during the period 1977-1980.

The nonparametric sign test was used to compare kill-per-set rates during daylight and darkness sets for both groups of operators, and showed that kill rates during darkness sets are significantly higher ($p \leq .001$) in both cases. This test also showed that kill rates during during daylight and darkness sets, for operators with the lowest rates, were each significantly lower than either of those rates for operators with the highest rates ($p \leq .001$).

These indices of the spread of generalized fleet performance allow us to consider the possible range of mortality reduction that may result from training and education. If assumed that each operator could become as skilled and motivated as the average of the 10 most effective operators in our sample (Table

14), then the overall fleet kill-per-set would drop to 0.7, which is about one-fifth of the fleet average in the NMFS sample. However, the assumption that vessel operators can be trained to uniform performance seems unrealistic since the NMFS, the Expert Skippers Panel (ESP)[7] and the Porpoise Rescue Foundation (PRF)[8] had been actively involved in transferring known methods and gear to the fleet for over 4 years and there was still an eight-fold difference in generalized kill rates between the two groups of operators for the period 1977-1980. This is most likely caused by the turnover of operators in the fleet, the progressive deterioration of equipment and basic differences in capabilities of the operators themselves. None of these factors are likely to be seriously affected by training programs, although this spread may be narrowed by concentrating training efforts on new and poorer performing operators.

Some factors which influence kill rates in daylight sets are the same as those influencing kill rates in darkness sets, one exception being the use of lights during darkness sets. Even for the most effective operators, these factors are aggravated enough by darkness to result in the average kill rate for darkness sets to be 2.4 times higher than the average kill rate for daylight sets. Testimony at the 1980 ALJ hearings (MMPAH-80, Coe)[9] pointed out that hand rescue efforts were less efficient in sets where backdown occurred in the dark, presumably because of reduced visibility. The overall effect of reduced visibility on backdown efficiency cannot be specifically measured nor can the effects of changes in tuna and dolphin behavior in response to darkness be assessed. These unmeasured factors can be considered as intrinsic to darkness sets such that, in the absence of improved technology, it is expected that the average long-term kill-per-set for darkness sets will be roughly 2.5 times the average kill-per-set for daylight sets regardless of education and training.

The target of education programs are those operators whose kill-per-set in darkness sets is 3.5 times their kill-per-set in daylight sets. Even in the absence of new technology, operator training may be able to reduce their rates to approach the 2.5 ratio of kill rates demonstrated by the most effective operators. Since some of the factors influencing kill rates for daylight sets are the same as those influencing kill rates for darkness sets, these training programs may effectively reduce the long-term kill rates for the poorer performing operators. A quantitative assessment of the potential overall reduction in total kill or fleet kill rates, due to training, is not possible because the degree to which the level of operator education and training has influenced the dispersion of generalized kill rates in our sample cannot be separated from the effect of the condition of the vessel and its equipment and the natural differences in operator capabilities. The extent to which current programs have already narrowed the spread of fleet performance through education also cannot be estimated.

A somewhat different approach was to consider the role of

education by examining the contribution of individual operators to the total daylight and darkness kill in our sample. Table 16 ranks the 20 operators who contributed most to the total daylight kill and 20 operators who contributed the most to the total darkness kill. Only seven operators appear in both lists which tends to support the supposition that accidental events that lead to rare, very high-kill sets may be more responsible for an operator appearing in this list than his general lack of skill or education. Secondly, the kill during darkness sets is concentrated among 20 operators. Out of 123 operators who made sets where backdown occurred during darkness, the 20 poorest performers accounted for 71.0% of the kill during darkness sets (22.2% of the total sample kill), with 52.7% of the kill during darkness sets (4,173 of 7,919) attributed to the 10 least effective operators. The 20 poorest performers of the 151 operators making sets where backdown occurred during daylight, killed 44.2% of the kill attributed to daylight sets (30.4% of the total sample kill). The 10 poorest performers during daylight sets killed 29.3% (5,093 of 17,398) of the total kill attributed to daylight sets.

If it is assumed that the 10 poorest performing operators in both daylight and darkness sets could be educated to perform at the mean kill-per-set level while all others remained unchanged, the kill during daylight sets would be reduced by 3,397 dolphins and the kill during darkness sets would be reduced by 2,788 (Table 15). The kill-per-set for darkness sets would decrease from 11.0 to 7.1, a 35% reduction. The kill-per-set in the daylight sets would drop from 2.5 to 2.0, a 20% reduction. The fleet average kill-per-set for all sets would drop from 3.3 to 2.5, a 24% reduction. This presupposes that education will somehow eliminate the very high kill sets that caused some of these operators to appear near the top of this list in the first place. Whether diligent application of the best gear and techniques could have prevented these sets cannot be adequately assessed from the database.

Discussion

The above analyses permit the following conclusions: 1) there is substantial justification for the development under the MMPA of a specific policy to reduce or eliminate marine mammal mortality associated with purse-seine sets in which the backdown procedure takes place in the dark, 2) this policy can be expressed by a regulatory prohibition on the initiation of sets involving dolphins within 90 minutes of local sunset, and 3) the impact of such a regulation on the tuna purse-seine fleet catch would be negative but small. The calculations which lead to conclusion number two, however, are based on the assumption that the regulation is enforced and complied with completely. In fact, efficiency of the policy as expressed through the sundown set prohibition is directly proportional to the level of compliance by the operators. These relationships give rise to some

interesting considerations as to how efficiently the regulation will reflect the intent of the policy.

Since compliance is the key to successful implementation of this policy, an examination of the motivations of the implementors at the operation level is instructive. First, in the U.S. tuna fishery, the implementors of policy via the sundown set prohibition are the same individuals who will suffer the direct negative impact of its implementation, i.e., the vessel captains and crews. Second, the only enforcement mechanism in operation on the high seas has been the NMFS observer program which was disabled for a period by a Federal District Court ruling, John R. Balelo et al. vs. Malcolm Baldridge, 519 f., District Court ruling, John R. Balelo et al. VS Malcolm Baldridge, 519 f., Supp. 573 (S.D., Cal. 1981). Third, neither the NMFS or IATTC observer programs have provided 100% coverage for even the U.S.-flag fleet. Fourth, concerning common property arrangements and the associated incentive structures, Young (1982) states:

> "The fact that there are no exclusive or private property rights to stocks of fish as such inevitably gives every fisherman a distinct incentive to ignore rules aimed at promoting conservation or economically efficient harvesting practices so long as he cannot be certain that others will comply with these rules. Partly, the prospects for compliance in the absence of enforcement are undermined by the facts that violation of rules in this realm are not generally obvious to the outside world while the major fisheries involve large enough stakes to offer a substantial temptation to violate or circumvent the relevant rules."

Fifth, through MMPA regulations, NMFS has repeatedly succeeded in effecting reductions in dolphin kill rates in the U.S. tuna purse-seine fishery. Prior to 1981 the gear and procedural requirements in these regulations were based upon proven advancements in fishing technology, which, in combination with annual kill quotas, provided vessel operators with the incentive and means to comply with the law while maintaining production. The use of quotas, which were perceived as potentially limiting to Industry production, forced rapid introduction of gear and procedures and heightened awareness within the Industry. Vessel operators at sea, as the ultimate agents for implementation of these regulations, found that with practice they could successfully employ these procedures and equipment. Future attempts at regulation should derive from a more complete understanding of the organizational, social, economic and technical aspects of the industry.

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Footnotes

[1] Dolphin, porpoise or marine mammal in this paper are used as general terms referring to all small cetaceans impacted in the fishery. Mortality or kill refers to dolphin mortality incidental to the catch of yellowfin and skipjack tunas. The unit of fishing effort "set" is defined as a single deployment of a purse-seine around an aggregation of dolphin or tuna. Tuna catches are estimated and expressed in short tons.

[2] Smith, T.D. 1979. Report of the Status of Porpoise Stock Workshop. Southwest Fish. Ctr. Admin. Rep. LJ-79-41, 120p.

[3] NOAA. 1980a. Draft Environmental Impact Statement: Proposed regulations and conditions for the issuance of a general permit governing the taking of marine mammals associated with tuna purse seining operations. Dept. of commerce, National Oceanic and Atmospheric Administration, NMFS, February 1980, 88p. plus appendices.

[4] NOAA. 1980b. Draft Environmental Impact Statement: Proposed regulations and conditions for the issuance of a general permit governing the taking of marine mammals associated with tuna purse seining operations. Dept. of commerce, National Oceanic and Atmospheric Administration, NMFS, November 1980, 51p. plus appendices.

[5] Coan, A.L., K.E. Wallace, and A.R. Jackson. 1988. Comparisons of dolphin mortality rates between day and night sets for the U.S. eastern tropical Pacific tuna purse seine fishery. Southwest Fisheries Center, National Marine Fisheries Service. December 1988. Administrative Report, LJ-88-29. 23p.

[6] IATTC. 1983. Data extracted from Inter-American Tropical Tuna Commission (IATTC) statistics on single set logbook data provided by vessel operators. Inter-American Tropical Tuna Commission, Scripps Institution of Oceanography, La Jolla California.

[7] Expert Skippers Panel. American Tunaboat Association, 1 Tuna Lane, San Diego, California.

[8] Porpoise Rescue Foundation. 7169 Construction Court, San Diego, California.

[9] MMPAH-80, Coe. 1980. Transcripts of Marine Mammal protection Act Administrative Law Judge Hearings on proposed regulations to govern the taking of marine mammals incidental to commercial fishing operations, March 31 to April 5, 1980. Available through NMFS Office of Marine Mammals and Endangered Species, NOAA, Department of Commerce, Page Bldg. 2, 3300 Whitehaven St. N.W., Washington, D.C.

Table 1. National Marine Fisheries Service (NMFS) and Inter-American Tropical Tuna Commission (IATTC) trips, identified by cruise number, used in this study.

NMFS Cruises										IATTC Cruises	
1977			1978			1979		1980		1979	1980
217	264	304	333	374	416	455	508	571	663	2	46
218	265	305	334	375	417	456	509	572	664	3	47
219	266	306	335	376	418	457	510	573	668	4	48
220	267	307	336	377	419	458	511	574	669	5	49
221	268	308	338	379	420	459	512	576	672	6	50
222	269	309	339	380	421	460	514	580		7	51
223	270	312	340	381	422	461	517	584		11	52
226	271	313	341	382	423	462	518	585		13	53
230	272	314	342	383	424	465	521	586		14	54
231	273	315	343	384	425	467	522	588		15	55
233	274	316	344	385	426	468	523	589		16	57
235	275	317	345	386	427	469	526	591		18	60
236	276	318	346	387	429	470	527	593		19	61
237	277	320	347	388	430	472	528	595		20	62
238	278	321	348	389	431	474	529	597		21	64
239	279	322	349	390	432	476	530	605		22	65
240	280	323	350	391	433	477	531	609		23	68
241	281	324	351	392	434	478	534	610		24	69
242	282	326	352	393	435	479	536	614		26	107
243	283	327	353	394	436	480	539	616		28	
244	284	328	354	395	437	482	540	617		29	
245	285	329	355	396	438	483	541	619		30	
246	286	331	356	397	439	484	542	621		31	
247	287	332	357	398	440	485	545	622		32	
248	288		358	399	441	486	546	623		33	
249	289		359	400	442	487	547	626		34	
250	290		360	401	443	489	550	629		35	
251	291		361	402	444	490	551	631		36	
252	292		362	403	445	491	552	632		37	
253	293		363	404	446	492	555	635		38	
254	294		364	405	447	493	556	641		39	
255	295		365	406	448	494	559	643		40	
256	296		366	407	449	495	561	644		41	
257	297		367	408	450	497	562	647		42	
258	298		368	409	451	498	565	651			
259	299		369	410	452	499	566	652			
260	300		370	411	453	500	567	653			
261	301		371	413	454	501	568	654			
262	302		372	414		502		658			
263	303		373	415		506		662			
Total No. of trips	104			118		78		45		34	19

Table 2. Calculated local apparent times of celestial events for dolphin sets in the 1979 observer sample.

	RANGE			Standard		25%	75%	
	Earliest	Latest	Mean	deviation	Median	quartile	quartile	Mode
SUNSET	1720	1940	1833	24.77	1831	1816	1854	1815
END CIVIL TWILIGHT	1744	2004	1855	24.88	1853	1838	1916	1850
END ASTRONOMICAL TWILIGHT	1837	2101	1947	25.63	1944	1928	2007	1941

Table 3. Characteristics of the time interval ("net let go" to "end of backdown") for 1979 observed sets which were initiated at 1630 hours or later (422 sets).

INTERVAL	MINUTES
Minimum	50
Maximum	266
Mean	87.5
SD of Mean	21.8
Mode	75
Median	83
25% Quartile	75
75% Quartile	96

Table 4. The distribution of dolphin sets by year, stratified to sundown and non-sundown sets with backdown during darkness or daylight.

	Non-Sundown Sets				Sundown Sets				Combined			
	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]
Darkness Sets	14	13	16	6	195	129	241	111	209	142	257	117
Daylight Sets	2671	1411	1681	860	88	41	64	28	2759	1452	1745	888
Combined	2685	1424	1697	866	283	170	305	139	2968	1594	2002	1005

[1] Data for 1980 are incomplete.

Table 5. The distribution of yellowfin tuna catch (in short tons) during dolphin sets by year, stratified to sundown and non-sundown sets with backdown during darkness or daylight.

	Non-Sundown Sets				Sundown Sets				Combined			
	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]
Darkness Sets	175	178	122	95	2545	1572	3076	1173	2720	1750	3198	1268
Daylight Sets	34018	17114	18540	9246	901	590	750	218	34919	17704	19290	9464
Combined	34193	17292	18662	9341	3446	2162	3826	1391	37639	19454	22488	10732

[1] Data for 1980 are incomplete.

Table 6. The distribution of dolphin kill by year, stratified to sundown and non-sundown sets with backdown during darkness or daylight.

	Non-Sundown Sets				Sundown Sets				Combined			
	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]
Darkness Sets	46	131	204	879	1310	1684	2751	775	1356	1815	2955	1654
Daylight Sets	7591	4243	2741	1971	157	88	412	29	7748	4331	3153	2000
Combined	7637	4374	2945	2850	1467	1772	3163	804	9104	6146	6108	3654

[1] Data for 1980 are incomplete.

Table 7. The distribution of dolphin kill-per-set by year, stratified to sundown and non-sundown sets with backdown during darkness or daylight.

	Non-Sundown Sets				Sundown Sets				Combined			
	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]
Darkness Sets	3.3	10.1	12.8	146.5	6.7	13.1	11.4	7.0	6.5	12.8	12.0	14.1
Daylight Sets	2.8	3.0	1.6	2.3	1.8	2.1	6.4	1.0	2.8	3.0	1.8	2.2
Combined	2.8	3.1	1.7	3.3	5.2	10.4	10.4	5.8	3.1	3.9	3.1	3.6

[1] Data for 1980 are incomplete.

Table 8. The distribution of dolphin kill-per-ton of yellowfin tuna by year, stratified to sundown and non-sundown sets with backdown during darkness or daylight.

	Non-Sundown Sets				Sundown Sets				Combined			
	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]
Darkness Sets	0.3	0.7	1.7	9.2	0.5	1.1	0.9	0.7	0.5	1.0	0.9	1.3
Daylight Sets	0.2	0.2	0.1	0.2	0.2	0.1	0.5	0.1	0.2	0.2	0.2	0.2
Combined	0.2	0.2	0.2	0.3	0.4	0.8	0.8	0.6	0.2	0.3	0.3	0.3

[1] Data for 1980 are incomplete.

Table 9. The distribution of catch of yellowfin tuna (short tons) per dolphin set by year, stratified to sundown and non-sundown sets with backdown during darkness or daylight.

	Non-Sundown Sets				Sundown Sets				Combined			
	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]
Darkness Sets	12.5	13.7	7.6	15.8	13.0	12.2	12.8	10.6	13.0	12.3	12.4	10.8
Daylight Sets	12.7	12.1	11.0	10.8	10.2	14.4	11.7	7.8	12.6	12.2	11.0	10.6
Combined	12.7	12.1	11.0	10.8	12.2	12.7	12.5	10.0	12.7	12.2	11.2	10.7

[1] Data for 1980 are incomplete.

Table 10a. Distribution of the percentage of sets, yellowfin tuna catch, and dolphin kill stratified to sundown and non-sundown sets with backdown during darkness or daylight for 1977.

	Non-Sundown Sets			Sundown Sets			Combined		
	SETS	CATCH	KILL	SETS	CATCH	KILL	SETS	CATCH	KILL
Darkness Backdown (BD) Sets:									
% of Darkness BD	6.7	6.4	3.4	93.3	93.6	96.6	100.0	100.0	100.0
% of Total	0.5	0.5	0.5	6.6	6.8	14.4	7.1	7.2	14.9
Daylight Backdown (BD) Sets:									
% of Daylight BD	96.8	97.4	98.0	3.2	2.6	2.0	100.0	100.0	100.0
% of Total	90.0	90.4	83.4	3.0	2.4	1.7	93.0	92.8	85.1
Combined:	90.5	90.8	83.9	9.5	9.2	16.1	100.0	100.0	100.0

Table 10b. Distribution of the percentage of sets, yellowfin tuna catch, and dolphin kill stratified to sundown and non-sundown sets with backdown during darkness or daylight for 1978.

	Non-Sundown Sets			Sundown Sets			Combined		
	SETS	CATCH	KILL	SETS	CATCH	KILL	SETS	CATCH	KILL
Darkness Backdown (BD) Sets:									
% of Darkness BD	9.2	10.2	7.2	90.8	89.8	92.8	100.0	100.0	100.0
% of Total	0.8	0.9	2.1	8.1	8.1	27.4	8.9	9.0	29.5
Daylight Backdown (BD) Sets:									
% of Daylight BD	97.2	96.7	98.0	2.8	3.3	2.0	100.0	100.0	100.0
% of Total	88.5	88.0	69.0	2.6	3.0	1.4	91.1	91.0	70.4
Combined:	89.3	88.9	71.2	10.7	11.1	28.8	100.0	100.0	100.0

Table 10c. Distribution of the percentage of sets, yellowfin tuna catch, and dolphin kill stratified to sundown and non-sundown sets with backdown during darkness or daylight for 1979.

	Non-Sundown Sets			Sundown Sets			Combined		
	SETS	CATCH	KILL	SETS	CATCH	KILL	SETS	CATCH	KILL
Darkness Backdown (BD) Sets:									
% of Darkness BD	6.2	3.8	6.9	93.8	96.2	93.1	100.0	100.0	100.0
% of Total	0.8	0.5	3.3	12.0	13.7	45.0	12.8	14.2	48.3
Daylight Backdown (BD) Sets:									
% of Daylight BD	96.3	96.1	86.9	3.7	3.9	13.1	100.0	100.0	100.0
% of Total	84.0	82.4	44.9	3.2	3.3	6.7	87.2	85.7	51.6
Combined:	84.8	83.0	48.2	15.2	17.0	51.8	100.0	100.0	100.0

Table 10d. Distribution of the percentage of sets, yellowfin tuna catch, and dolphin kill stratified to sundown and non-sundown sets with backdown during darkness or daylight for 1980 (incomplete).

	Non-Sundown Sets			Sundown Sets			Combined		
	SETS	CATCH	KILL	SETS	CATCH	KILL	SETS	CATCH	KILL
Darkness Backdown (BD) Sets:									
% of Darkness BD	5.1	7.5	53.1	94.9	92.5	46.9	100.0	100.0	100.0
% of Total	0.6	0.9	24.1	11.0	10.9	21.2	11.6	11.8	45.3
Daylight Backdown (BD) Sets:									
% of Daylight BD	96.8	97.7	98.6	3.2	2.3	1.4	100.0	100.0	100.0
% of Total	85.6	86.2	53.9	2.8	2.0	0.8	88.4	88.2	54.7
Combined:	86.2	87.0	78.0	13.8	13.0	22.0	100.0	100.0	100.0

Table 11. The percentage of "problem sets" (dolphin kill greater than 15) by year, stratified to sundown and non-sundown sets with backdown during darkness or daylight.

	Non-Sundown Sets				Sundown Sets				Combined			
	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]	1977	1978	1979	1980[1]
Darkness Sets	7.1	23.1	31.2	33.4	13.9	12.4	12.9	9.9	12.4	13.3	14.0	11.2
Daylight Sets	4.0	3.2	2.4	2.0	3.3	0.0	3.2	0.0	4.0	3.0	2.4	2.0
Combined	4.1	3.4	2.7	2.2	10.6	9.4	10.5	7.9	4.6	3.9	3.9	3.1

[1] Data for 1980 are incomplete.

Table 12. Estimated yellowfin and skipjack tuna catches, in short tons, from the Pacific Ocean east of 150° W by U.S.-flag purse seiners during 1977-1980[1].

Year	Taken on dolphin herds		Taken on other than dolphin herds		Combined	
	Yellowfin	Skipjack	Yellowfin	Skipjack	Yellowfin	Skipjack
1977	93,391	4,358	42,116	45,679	135,507	50,037
1978	47,398	1,093	67,939	104,072	115,337	105,165
1979	66,703	1,331	60,423	72,643	127,126	73,974
1980	56,970	2,253	55,955	92,437	112,925	94,690

[1] Estimated from Inter-American Tropical Tuna Commission (IATTC) statistics on single-set logbook data provided by vessel operators. These estimates may differ slightly from others calculated by other methods from IATTC data.

Table 13. Cumulative average of the observed annual dolphin kill and tuna catch for 1,236 sets that were initiated, in 10-minute intervals, before and after sunset, 1977-1979. Catch includes yellowfin and skipjack.

	Dolphin Kill			Tuna Catch		
Time relative to sunsct (minutes)	Mean cumulative observed (number)	Range (number)	% of Mean	Mean culmulative observed (tons)	Range (tons)	% of Mean
-130	2548	1976-3522	31.0	4822	3036-6388	15.7
-120	2468	1961-3427	30.0	4343	2912-5443	14.2
-110	2348	1838-3396	28.6	3876	2604-4697	12.7
-100	2249	1769-3300	27.3	3542	2389-4192	11.6
-90	2153	1646-3175	26.2	3209	2140-3917	10.5
-80	1867	1386-2607	22.7	2770	1794-3557	9.1
-70	1695	1255-2488	20.6	2370	1501-3199	7.8
-60	1397	1166-1845	17.0	1985	1237-2592	6.5
-50	1040	823-1325	12.6	1518	943-1875	5.0
-40	911	803-1031	11.1	1224	780-1517	4.0
-30	637	520- 793	7.7	789	648- 980	2.6
-20	450	312- 599	5.6	499	301- 601	1.6
-10	379	212- 552	4.6	292	187- 414	1.0
0 sunset	308	133- 548	3.7	197	121- 236	0.6
+11	228	9- 504	2.8	109	10- 168	0.4
+>21	149	0- 440	1.8	30	1- 50	0.1
Total annual average	8,222			30,560		

Table 14. The 10 "most effective" operators ranked by overall kill-per-set using operators with at least 8 dark backdown sets. Data from the 1977-1980 NMFS data base.

		Daylight Backdown			Dark Backdown		
		Kill-per-set			Kill-per-set		
Rank	Operator Code Pseudonym	N (sets)	MEAN	SD	N (sets)	MEAN	SD
1	395	115	0.2	0.73	9	0.6	1.13
2	74	113	0.2	0.73	8	0.0	0.00
3	164	58	0.3	1.55	9	0.7	1.66
4	574	79	0.3	0.74	12	0.9	1.00
5	885	63	0.3	1.46	9	3.3	7.12
6	935	68	0.8	1.82	13	0.9	2.56
7	585	135	1.0	2.91	17	1.1	2.09
8	474	72	0.9	2.80	9	2.3	2.74
9	225	179	1.0	8.51	15	2.7	4.86
10	545	81	1.2	3.82	12	2.7	6.85
		963	0.6		113	1.5	
		Dark Backdown Differential: 0.90/set Dark Backdown Factor: 2.4 * Daylight Backdown rate					

Table 15. The 10 "least effective" operators ranked by overall kill-per-set using operators with at least 8 dark backdown sets. Data from the 1977-1980 NMFS data base.

		Daylight Backdown			Dark Backdown		
		Kill-per-set			Kill-per-set		
Rank	Operator Code Pseudonym	N (sets)	MEAN	SD	N (sets)	MEAN	SD
1	794	43	4.4	19.10	9	36.4	63.53
2	565	134	8.0	22.76	29	15.8	22.57
3	384	122	5.6	18.66	17	23.0	75.46
4	864	65	1.2	3.90	19	28.9	102.03
5	675	89	6.1	32.50	9	6.2	10.32
6	744	60	4.2	14.59	13	9.7	14.60
7	644	61	3.9	8.90	13	7.2	14.04
8	365	112	3.3	14.26	12	10.1	14.31
9	155	76	3.3	16.08	17	5.7	12.58
10	55	14	2.4	5.11	8	5.4	7.17
		776	4.2		146	14.8	
		Dark Backdown Differential: 10.59/set Dark Backdown Factor: 3.5 * Daylight Backdown rate					

Table 16. The twenty vessel operators who contributed most to the total observed daylight backdown kill and the twenty who contributed most to the total observed dark backdown kill. Data from the 1977-1980 NMFS data base.

	DAYLIGHT BACKDOWN					DARK BACKDOWN				
Rank	Operator Code Pseudonym	Number Killed	% Total Kill	Number Sets	% of Total Sets	Operator Code Pseudonym	Number Killed	% of Total Kill	Number Sets	% of Total Sets
1	565	1080	6.2	134	2.0	334	882	11.1	3	0.4
2	384	681	3.9	122	1.8	864	549	6.9	19	2.6
3	664	629	3.6	27	0.4	565	458	5.8	29	4.0
4	675	544	3.1	89	1.3	65	438	5.5	4	0.6
5	694	421	2.4	56	0.8	384	392	5.0	17	2.4
6	945	379	2.2	42	0.6	794	328	4.1	9	1.2
7	365	375	2.2	112	1.6	84	320	4.0	20	2.8
8	705	340	2.0	42	0.6	294	281	3.6	2	0.3
9	844	337	1.9	33	0.5	355	265	3.3	7	1.0
10	344	307	1.8	12	0.2	735	260	3.3	13	1.8
11	305	307	1.8	168	2.4	194	223	2.8	3	0.4
12	564	276	1.6	110	1.6	305	173	2.2	10	1.4
13	64	271	1.6	28	0.4	95	169	2.1	4	0.6
14	345	261	1.5	37	0.5	575	152	1.9	7	1.0
15	155	252	1.4	76	1.1	335	145	1.8	5	0.7
16	744	250	1.4	60	0.9	154	134	1.7	6	0.8
17	164	249	1.4	33	0.5	745	130	1.6	13	1.8
18	575	245	1.4	36	0.5	744	126	1.6	13	1.8
19	184	245	1.4	144	2.1	365	121	1.5	12	1.7
20	785	244	1.4	24	0.4	155	97	1.2	17	2.4
Totals		7693	44.2	1386	20.2		5622	71.0	214	29.7
Mean Kill-per-set:			5.7					26.3		
	Total Daylight Backdown Kill = 17,398 Total Daylight Backdown Sets = 6,862					Total Dark Backdown Kill = 7,919 Total Dark Backdown Sets = 722				

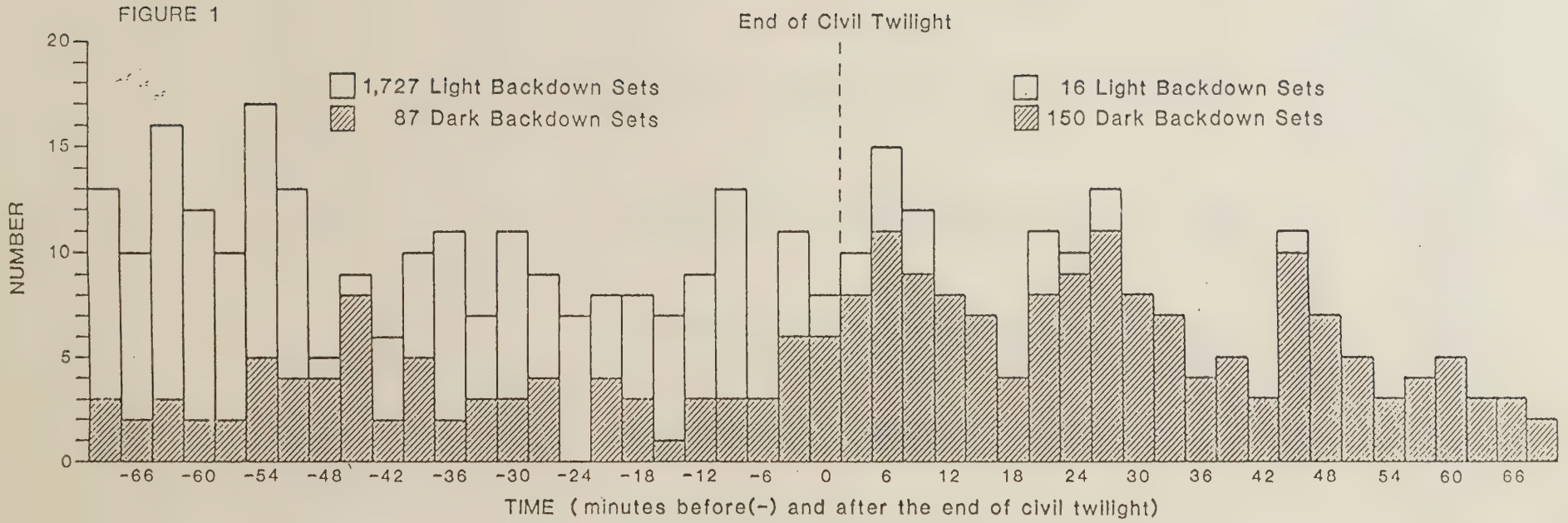


FIGURE 1
End of Civil Twilight
1,727 Light Backdown Sets
87 Dark Backdown Sets
16 Light Backdown Sets
150 Dark Backdown Sets
NUMBER
20
15
10
5
0
-66 -60 -54 -48 -42 -36 -30 -24 -18 -12 -6 0 6 12 18 24 30 36 42 48 54 60 66
TIME (minutes before(-) and after the end of civil twilight)

Figure 1. Distribution of dolphin sets in 1979, based on the time at the end of backdown recorded by the observer at sea, relative to the estimated end of civil twilight. NMFS data base.

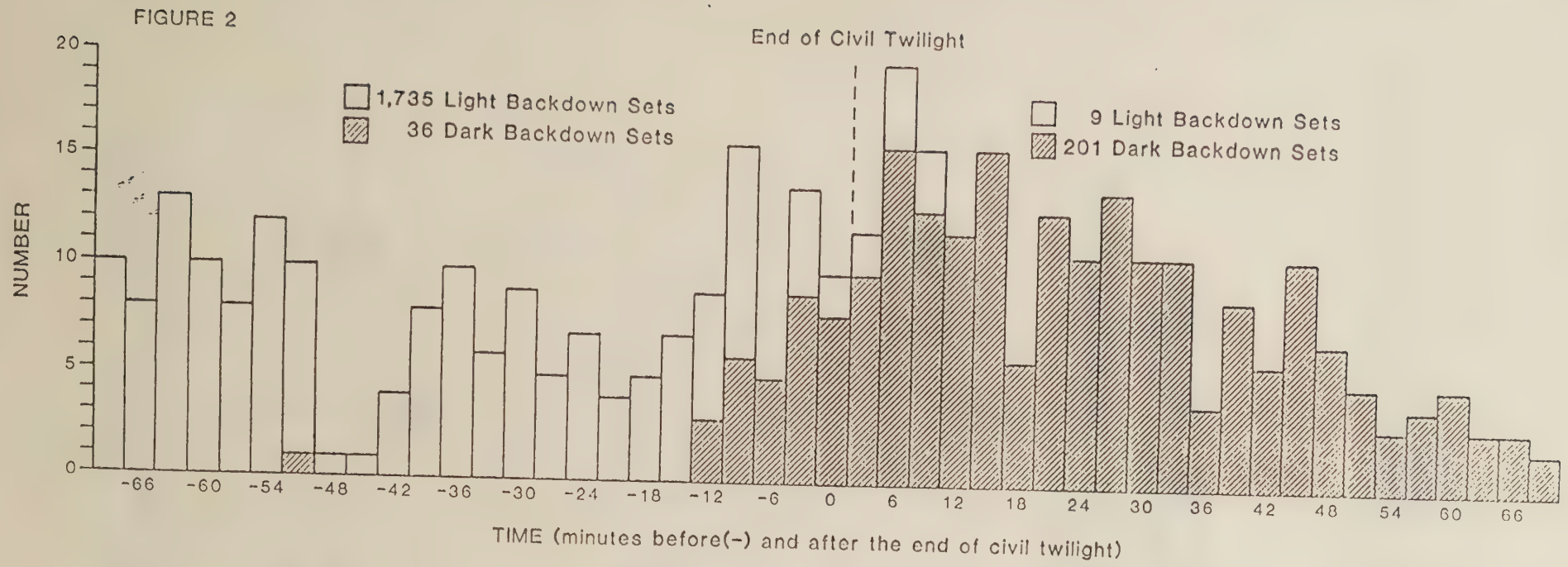
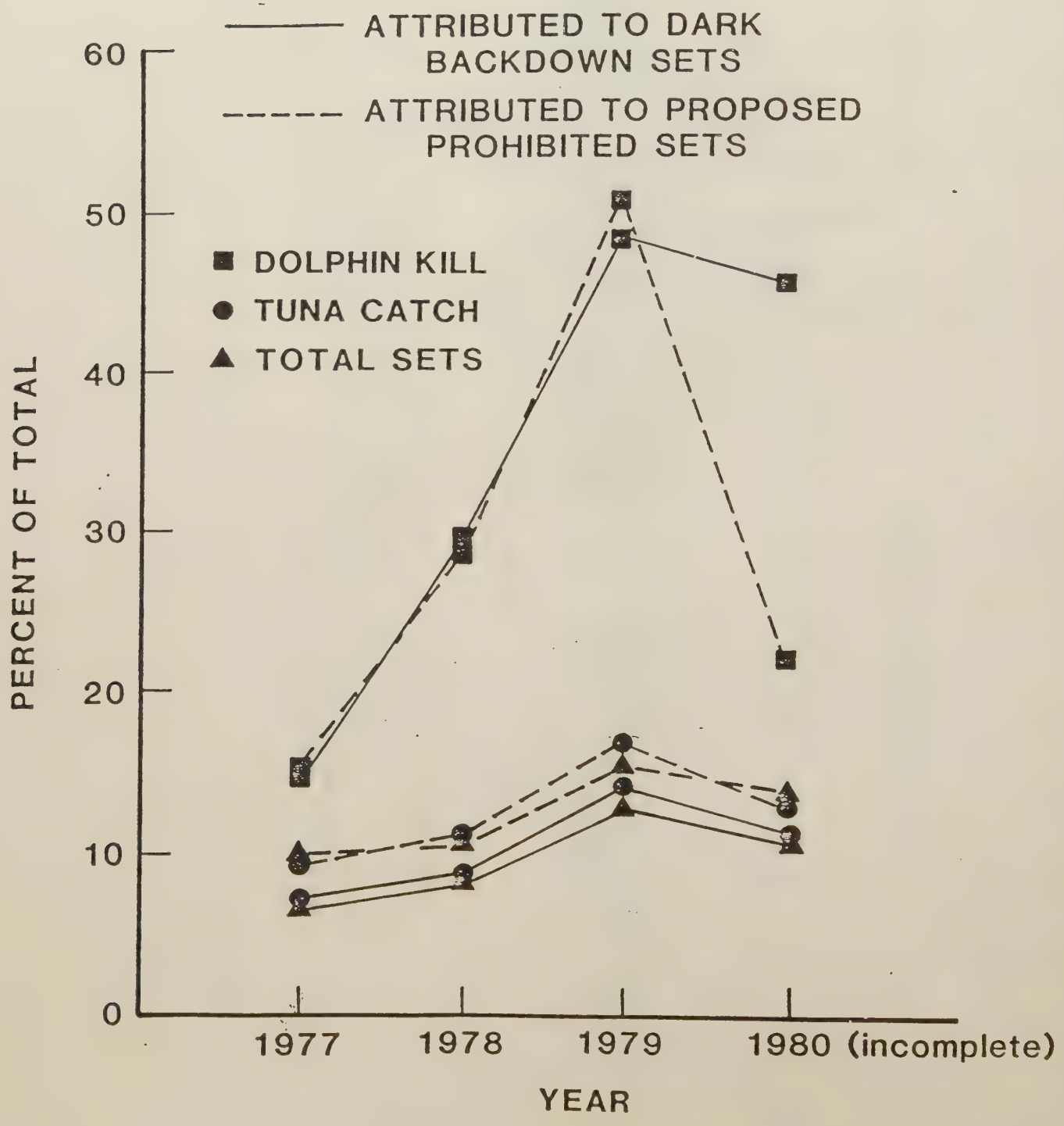


FIGURE 2
End of Civil Twilight
1,735 Light Backdown Sets
36 Dark Backdown Sets
9 Light Backdown Sets
201 Dark Backdown Sets
NUMBER
20
15
10
5
0
-66 -60 -54 -48 -42 -36 -30 -24 -18 -12 -6 0 6 12 18 24 30 36 42 48 54 60 66
TIME (minutes before(-) and after the end of civil twilight)

Figure 2. Distribution of dolphin sets in 1979, base on the corrected time at the end of backdown relative to the estimated end of civil twilight. Corrections were ±60 minutes based on information recorded by the observer at sea. NMFS data base.

Figure 3. The percentage of the total annual observed dolphin kill, tuna catch, and sets on marine mammals, resulting from dark backdown sets and sets that would have been prohibited during the period 1977-1980.



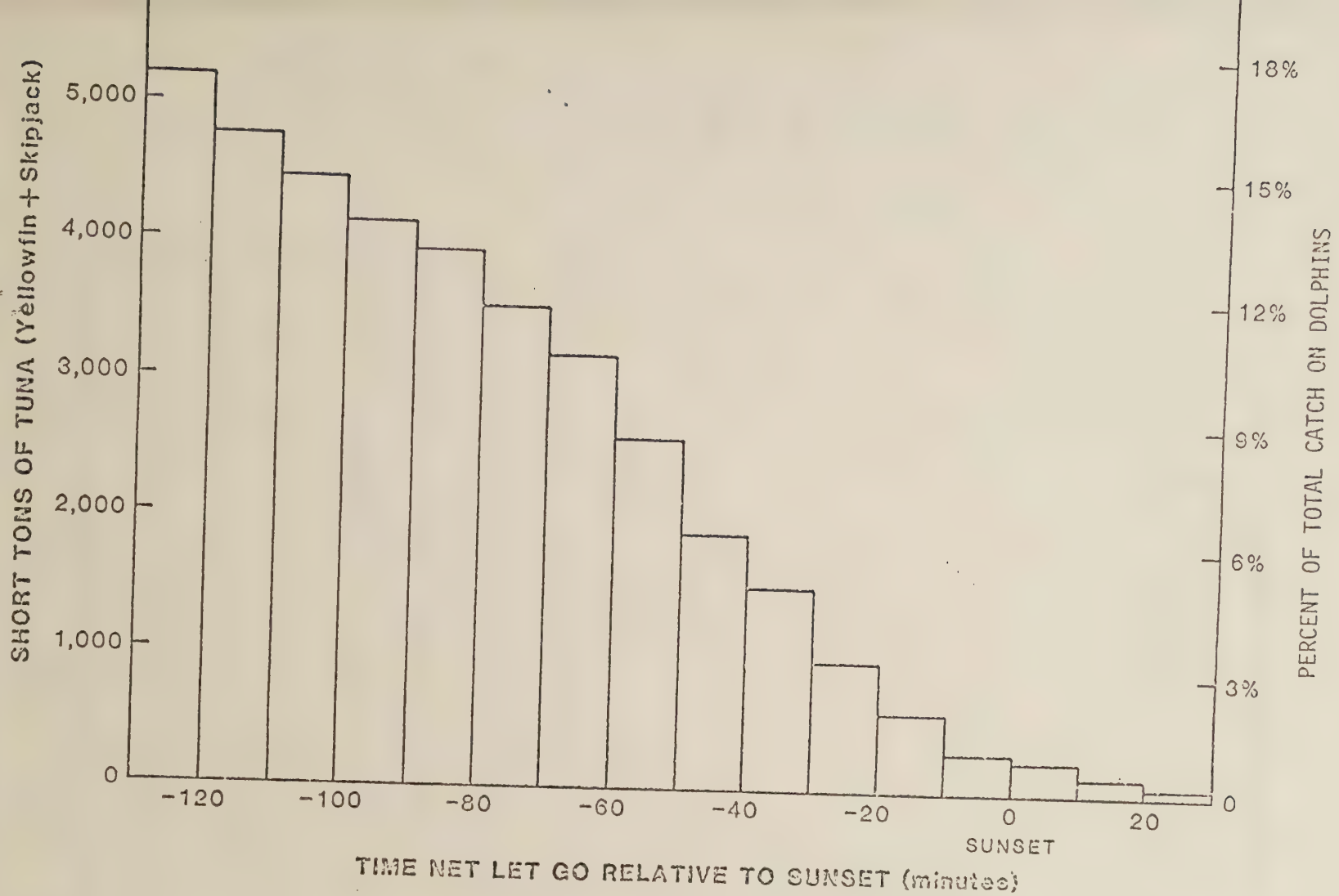


Figure 4. Cumulative tuna catch on dolphin schools by 10-minute intervals of "time net let go" relative to sunset for 1979 observed vessels. Total 1979 observed tuna catch on dolphins is 30165 short tons.

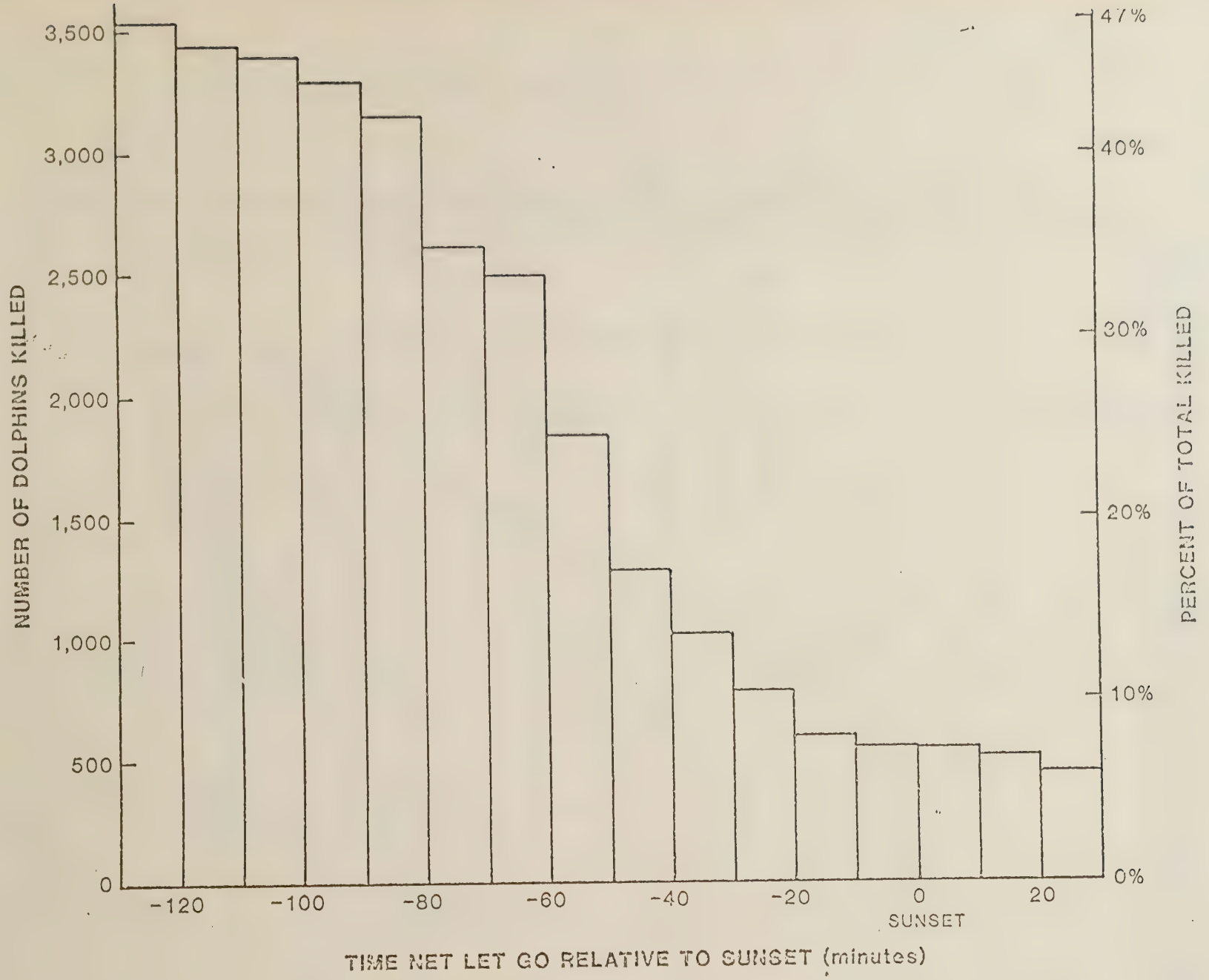


Figure 5. Cumulative number of dolphins killed by 10-minute intervals of "time net let go" relative to sunset for 1979 observed vessels. Total 1979 observed kill is 7458.

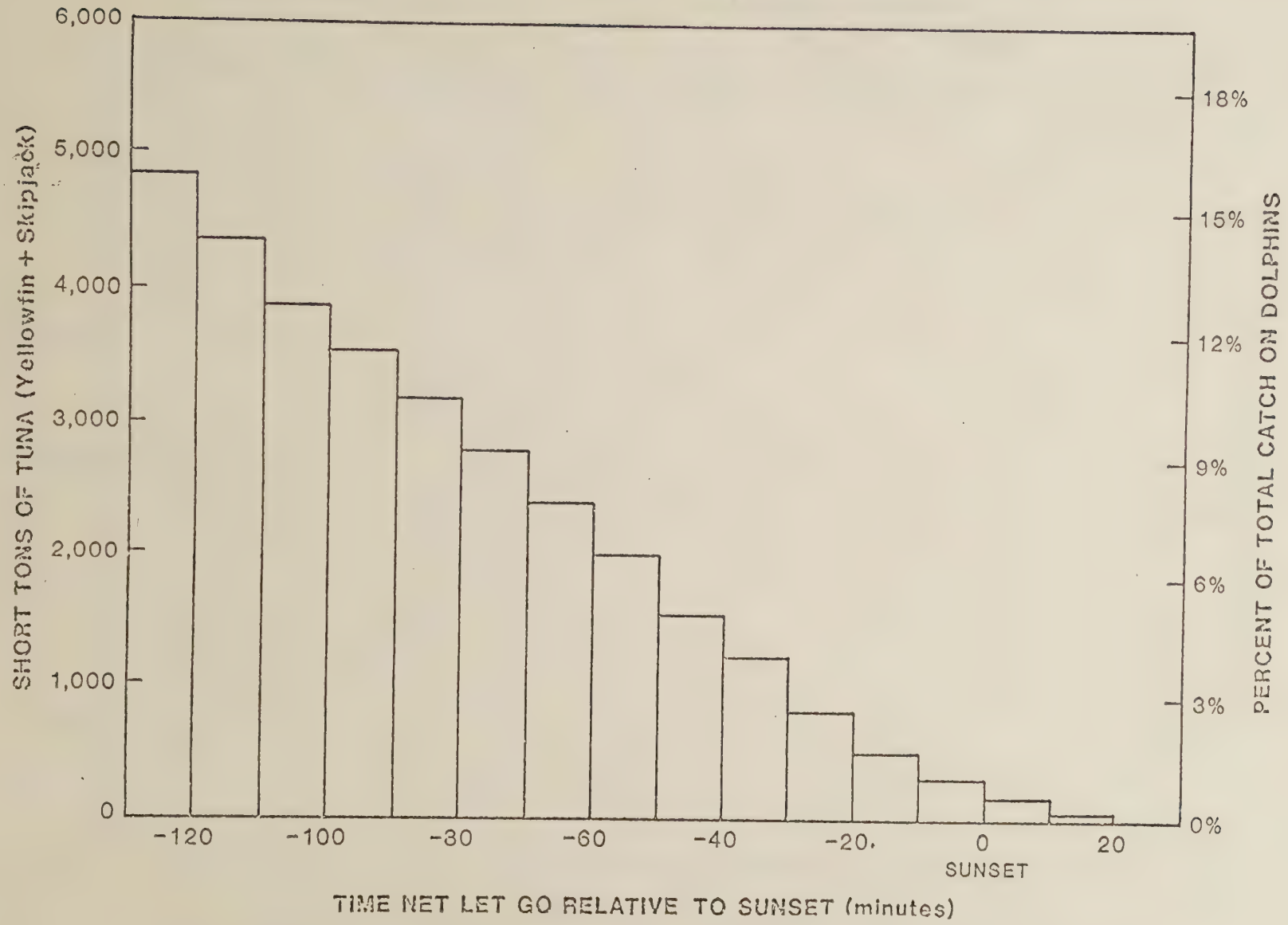


Figure 6. The cumulative average annual observed tuna catch on dolphin schools by 10-minute intervals of "time net let go" relative to sunset. Averages are based on all observed dolphin sets from 1977, 1978 and 1979. The average annual observed catch is 30560 short tons.

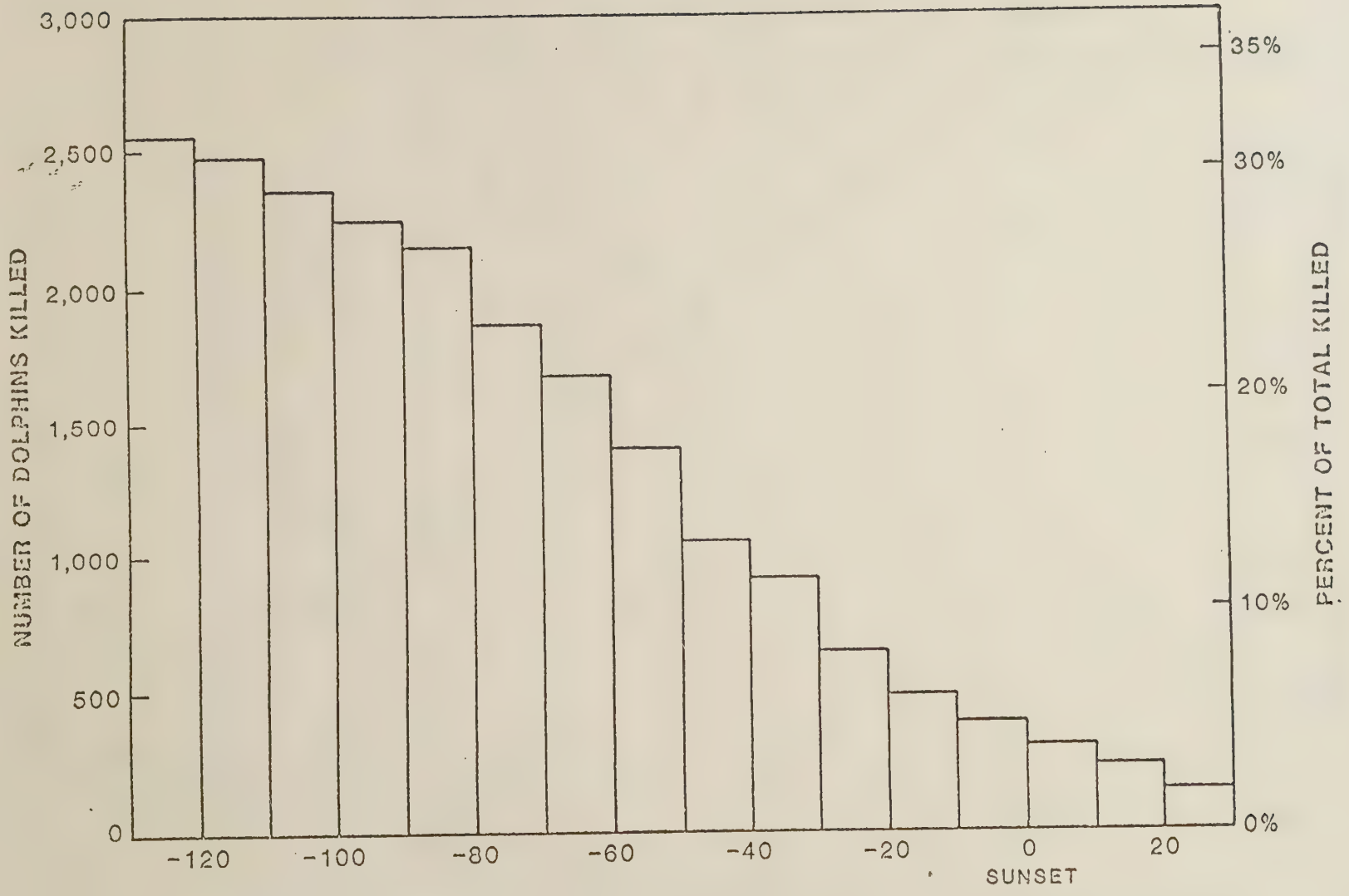


Figure 7. The cumulative average annual observed dolphin kill by 10-minute intervals of "time net let go" relative to sunset. Averages are based on all observed dolphin sets from 1977, 1978 and 1979. Average annual total observed kill is 8222.